THE EFFECT OF PRESSURE ON THE VISCOSITY OF GASES

BY

BERTRAND JESSE MAYLAND

B.S., University of Wisconsin, 1940

M.S., University of Illinois, 1942

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CHEMISTRY IN THE GRADUATE SCHOOL OF THE UNIVERSITY OF ILLINOIS, 1943

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Introduction

In recent years there has been a tendency to use higher pressures in many processes with which the chemical engineer is concerned. Although the methods of design of equipment are fairly sound in most cases involving fluid flow, there is often a lack of fundamental data on the effect of pressure on the properties of the materials being handled. A considerable amount of work has been done on the effect of pressure on the density of gases but there is relatively little data available for the other properties such as viscosity, diffusivity, and themal conductivity. One reason for the lack of data of this sort in the literature is the experimental difficulties associated with it. This is very well illustrated by the large discrepancies between sets of data obtained by two different investigators.

This investigation is concerned with a study of the effect of pressure on the viscosity of gases. Inasmuch as the viscosity at constant temperature may vary several hundred percent as the pressure is increased from atmospheric to above the critical pressure, data on the effect of pressure on the viscosity of gases is quite important to the designer of high-pressure equipment. Experimental data was obtained on three gases, ethylene, methane, and propane, and a general correlation was constructed with which high-pressure viscosities can be predicted where no data is available.

THEORETICAL

For an ideal gas the kinetic theory (4) indicates that the viscosity is independent of the pressure. For an actual gas, however, at pressures somewhat above atmospheric the viscosity shows an increase with increasing pressure. At low pressures the viscosity increases with increasing temperature, but at high pressures the behavior of gases is more like that

of liquids, i.e., the viscosity decreases with increasing temperature.

Any method applicable to the measurement of liquid viscosities can be used for the determination of the viscosity of gases. However, due to the low viscosity of gases and the rapid decrease of kinematic viscosity with increasing pressure, difficulty has been encountered with some types of viscometers in preventing turbulent conditions. When turbulence occurs the phenomenon observed is a combination of viscous drag and inertia effects. In general, although any viscometer can be calibrated in such a way that it can be used to determine viscosities even under turbulent conditions, the accuracy of the method is less satisfactory. An ideal viscometer would be one in which the inertia effects are negligible and the phenomenon observed is entirely due to the viscous drag. The method of transpiration of the fluid through a capillary tube is the most satisfactory for the direct determination of viscosity.

EXPERIMENTAL

A modification of the Rankine-type viscometer (7) was used in this investigation. The viscometer consisted of two parallel Pyrex-glass tubes joined at both ends. One tube was a heavy-wall capillary tube with 0.02246 cm. inside diameter and 86.70 cm. long. The other tube was a standard thin-wall Pyrex tube with 0.3 cm. inside diameter. The capillary tube was long relative to its diameter so that end-effects were minimized. A mercury pellet in the larger tube with a piston-like action forced the gas through the capillary. The weight of the pellet furnished the pressure drop across the capillary. For use at high pressures the glass viscometer was placed in a steel bomb and an external pressure of nitrogen was applied to balance the internal pressure of the gas sample.

To determine viscosities directly with a Rankine viscometer the diameter of the capillary must be known accurately since it occurs to the fourth power in the calculations. The diameter of the capillary was determined very carefully by W. J. Fisher's method (3) which consists of measuring the

length of a short thread (about 2 cm.) of mercury at various positions along the length of the tube. An average value of the diameter to the fourth power was obtained from a graphical integration.

The sample-gas compressor consisted of a mercury U-tube. The sample to be compressed was placed above the mercury in one leg and compressed nitrogen was fed into the other leg until the desired pressure was attained in the system. The pressure was read by two 12 inch Bourdon gages, one covered the range from 0 to 1200 psi and the other from 1200 to 3000 psi. The gages were calibrated at frequent intervals with a dead-weight gage.

The desired temperatures were obtained by means of electrical heating coils wound on the outside of the bomb. The temperature was controlled manually by varying the current to the various heating coils with a variable-voltage autotransformer. The temperature of the viscometer was measured at three points along its length with iron-constantan thermocouples. At all times during the course of a run the temperature was maintained within ± 0.3 degrees Centigrade of the desired temperature.

The rate of flow through the capillary was obtained from the time for the mercury pellet to fall from one pair of tungsten contacts to the other pair sealed through the wall of the pellet tube. The time of fall was obtained automatically since the timer was turned on and off electrically when the pellet passed the pairs of contacts.

No attempt was made to further purify the gases studied in this investigation. The ethylene and the propane were obtained from the Ohio Chemical Company. The ethylene was designated as 99.5% pure and the propane was 99.9% pure. The methane used came from the Buttonwillow field, California and it was designated as 99.7% pure. In all cases the nature of the impurity was not mentioned.

EXPERIMENTAL RESULTS

Pressure-viscosity isotherms were obtained for three gases, ethylene, methane, and propane. Tables 1, 2, and 3 give a

summary of the viscosity data obtained. Each value represents an average of a number of independent determinations of the viscosity using different size pellets. The values for atmospheric pressure were determined by extrapolation of the pressure-viscosity isotherms.

TABLE 1

SUMMARY OF VISCOSITY VALUES FOR ETHYLENE

Pressure in Atm.	Viscosity in Micropoises				
	30°C	40°C	50°C	70°C	95°C
1.00	105.4	107.4	109.3	117.2	125.5
5.08	106.0	108.0	109.9	118.0	125.8
28.2	113.1	115.0	119.2	124.3	129.5
48.6	129.9	130.6	130.5	133.6	138.9
55.4	140.6	136.9	136.2	138.1	142.6
67.3	177.5	159.2	150.5	147.4	149.8
79.1	254.5	200.3	172.1	160.6	158.9
89.3	304.7	248.3	197.5	173.6	168.1
103.1	359.2	299.7	239.6	191.9	181.8
137.0	434.7		320.3	255.8	226.5
171.0					277.3

TABLE 2

SUMMARY OF VISCOSITY VALUES FOR METHANE

Pressure in Atm.	Viscosity in Micropoises			
	30°C	50°	70°	95°
1.00	110.8	117.1	125.6	133.7
4.40	112.2	118.1	126.3	134.9
28.2	115.7	121.5	129.5	136.9
41.8	119.8	124.8	132.2	139.7
55.4	123.7	128.3	135.1	142.3
69.0	128.1	132.8	138.4	145.3
82.7	132.7	137.1	142.1	147.8
96.3	138.6	142.9	146.7	151.2
116.8	147.3	150.9	153.3	156.3
137.0	158.1	159.0	160.8	161.8
171.0				173.5

TABLE 3

SUMMARY OF VISCOSITY VALUES FOR PROPANE

Pressure in Atm.	Viscosity in Micropoises					
	30°C	37.7°	54.4°	71.1°	87.7°	105.4°
1.00	80.3	82.8	88.5	93.2	97.7	102.3
4.40	80.7	83.1	88.8	93.4	97.8	102.3
7.80	81.1	83.6	89.7	94.6	98.8	103.6
9.50	81.4					
11.2		84.5	90.6	95.4		
14.6			91.5	96.0	100.9	105.4
18.0			93.2	98.5		
21.4				100.7	107.5	108.4
28.3					119.2	115.2
35.0						124.8
41.8						156.9

The experimental results obtained in this investigation are believed to be accurate within 1% or 2% at most. The atmospheric viscosity values obtained by extrapolation agree within the accuracy of the results with values obtained by other investigators. The fact that results of this investigation check the results obtained by Comings and Egly (2) for ethylene using a similar viscometer verifies the accuracy of the method of calibration for direct determinations of viscosities.

CORRELATION OF EXPERIMENTAL DATA

Of the various types of correlation of viscosity data based on the law of corresponding states that have been proposed (5, 6, 8) it has been shown that the correlation of Comings and Egly (1) is the most general. Their correlation states that the viscosity ratio is the same for any gas at the same reduced temperature and reduced pressure. The viscosity ratio is defined as the ratio of the viscosity at any temperature and pressure to the viscosity at the same temperature but at a pressure sufficiently low so that the viscosity is independent of the pressure. The viscosity at atmospheric pressure is used.

After a critical survey of the viscosity data available, the most reliable data was used to prepare a general correlation. The correlation was prepared by plotting the viscosity ratio versus reduced pressure for constant reduced temperature. For reduced temperatures above $T_R=1$ the average correlation fits the data used in its construction very well. For reduced temperatures below $T_R=1$ and reduced pressure below $P_R=1$ the correlation does not fit quite so well. If the correlation is limited to hydrocarbons, the fit is much better for the region $T_R<1$ and $P_R<1$. Using the general correlation the viscosity of any hydrocarbon gas can be predicted within 5%. For other than hydrocarbon gases the correlation gives accurate results for $T_R>1$ but for $T_R<1$ the curve may give predictions 20% in error since the correlation in this region is based entirely on hydrocarbon data.

SUMMARY

Experimental viscosity data was obtained for ethylene, methane, and propane with an estimated accuracy within 2%.

The range covered for ethylene was from 5.08 to 171.0 atmospheres pressure and from 30 to 95 degrees Centigrade, for methane from 4.40 to 171.0 atmospheres and from 30 to 95 degrees Centigrade, and for propane from 4.40 to 41.8 atmospheres and from 30 to 104.5 degrees Centigrade.

Using all the reliable viscosity data available a general correlation chart was constructed with which the viscosity of any gas at a high pressure can be predicted if the viscosity at atmospheric pressure, the critical pressure, and the critical temperature are known. The correlation is capable of accuracy within 5% over most of the range.

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VITA

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